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U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

MAY 04 2001

TRADEMARK  
SEARCHED

**TRANSMITTAL LETTER TO THE UNITED STATES  
DESIGNATED/ELECTED OFFICE (DO/EO/US)  
CONCERNING A FILING UNDER 35 U.S.C. 371**

INTERNATIONAL APPLICATION NO.

PCT/FR99/02733

TITLE OF INVENTION

**Method and Device For Determining the Center of a Joint**

APPLICANT(S) FOR DO/EO/US

CINQUIN, Philippe et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1.  This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2.  This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3.  This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4.  The US has been elected by the expiration of 19 months from the priority date (Article 31).
5.  A copy of the International Application as filed (35 U.S.C. 371(c)(2))
  - a.  is attached hereto (required only if not communicated by the International Bureau).
  - b.  has been communicated by the International Bureau.
  - c.  is not required, as the application was filed in the United States Receiving Office (RO/US).
6.  An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
  - a.  is attached hereto.
  - b.  has been previously submitted under 35 U.S.C. 154(d)(4).
7.  Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
  - a.  are attached hereto (required only if not communicated by the International Bureau).
  - b.  have been communicated by the International Bureau.
  - c.  have not been made; however, the time limit for making such amendments has NOT expired.
  - d.  have not been made and will not be made.
8.  An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9.  An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). (unexecuted)
10.  An English language translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

**Item 11 to 20 below concern document(s) or information included:**

11.  An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12.  An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13.  A **FIRST** preliminary amendment.
14.  A **SECOND** or **SUBSEQUENT** preliminary amendment.
15.  A substitute specification.
16.  A change of power of attorney and/or address letter.
17.  A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
18.  A second copy of the published international application under 35 U.S.C. 154(d)(4).
19.  A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20.  Other items or information:

Acknowledgment postcard

ATTORNEY'S DOCKET NUMBER

Cinquin-1

U.S. APPLICATION NO. (If known, see 37 CFR 1.5)

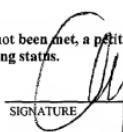
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PRIORITY DATE CLAIMED

10 November 1998

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PCT/FR99/02733INTERNATIONAL APPLICATION NO  
PCT/FR99/02733ATTORNEY'S DOCKET NUMBER  
Cinquin-1

21. <input checked="" type="checkbox"/> The following fees are submitted:		CALCULATIONS PTO USE ONLY	
BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)): Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO. ....		\$1000.00	
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO ..... International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO ..... International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) ..... International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) .....		\$860.00 \$710.00 \$690.00 \$100.00	
<b>ENTER APPROPRIATE BASIC FEE AMOUNT =</b>		\$ 1000.00	
Surcharge of \$130.00 for furnishing the oath or declaration later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(e)).		\$ 0.00	
CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE
Total claims	12 - 20 =	x \$18.00	\$ 0.00
Independent claims	2 - 3 =	x \$80.00	\$ 0.00
MULTIPLE DEPENDENT CLAIM(S) (if applicable)		+ \$270.00	\$ 0.00
<b>TOTAL OF ABOVE CALCULATIONS =</b>		\$ 1000.00	
<input checked="" type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.		\$ 500.00	
<b>SUBTOTAL =</b>		\$ 500.00	
Processing fee of \$130.00 for furnishing the English translation later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(f)).		\$ 0.00	
<b>TOTAL NATIONAL FEE =</b>		\$ 500.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). \$40.00 per property +		\$ 0.00	
<b>TOTAL FEES ENCLOSED =</b>		\$ 500.00	
		Amount to be refunded: \$	
		charged: \$	
<p>a. <input checked="" type="checkbox"/> A check in the amount of \$ 500.00 to cover the above fees is enclosed.</p> <p>b. <input type="checkbox"/> Please charge my Deposit Account No. _____ in the amount of \$ _____ to cover the above fees. A duplicate copy of this sheet is enclosed.</p> <p>c. <input checked="" type="checkbox"/> The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. <u>04-1679</u>. A duplicate copy of this sheet is enclosed.</p> <p>d. <input type="checkbox"/> Fees are to be charged to a credit card. <b>WARNING:</b> Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.</p>			
<p><b>NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137 (a) or (b)) must be filed and granted to restore the application to pending status.</b></p>			
SEND ALL CORRESPONDENCE TO:			
Arthur L. Plevy, Esq. Duane, Morris & Heckscher, LLP 100 College Road West, Suite 100 Princeton, New Jersey 08540			
 SIGNATURE <u>Arthur L. Plevy</u> NAME <u>24,277</u> REGISTRATION NUMBER			

**VERIFIED STATEMENT (DECLARATION) CLAIMING SMALL ENTITY STATUS**  
 (37 CFR 1.9 (f) and 1.27 (c)) — SMALL BUSINESS CONCERN

I hereby declare that I am

the owner of the small business concern identified below  
 an official of the small business concern empowered to act on behalf of the concern identified below:

NAME OF CONCERN UNIVERSITE JOSEPH FOURIER

ADDRESS OF CONCERN 621, Avenue Centrale, B.P. 53 X, 38041 GRENOBLE CEDEX, FRANCE

I hereby declare that the above-identified small business concern qualifies as a small business concern as defined in 13 CFR 121.3-18, and reproduced in 37 CFR 1.9(d), for purposes of paying reduced fees under section 41 (a) and (b) of Title 35, United States Code, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby declare that rights under contract of law have been conveyed to and remain with the small business concern identified above with regard to the invention, entitled METHOD AND DEVICE FOR DETERMINING THE CENTER OF A JOINT,  
 by inventors(s) Philippe CINQUIN, Laurent DESBAT, Stéphane LAVALLEE  
 described in

the specification filed herewith  
 Application Serial No. 09/831,170, filed May 4, 2001.  
 Patent No. \_\_\_\_\_, issued \_\_\_\_\_.

If the rights held by the above-identified small business concern are not exclusive, each individual, concern or organization having rights to the invention is listed below\* and no rights to the invention are held by any person, other than the inventor, who could not qualify as a small business concern under 37 CFR 1.9(d) or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e).

\*NOTE: Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27)

FULL NAME SAME AS ABOVE

ADDRESS

Individual       Small Business Concern       Nonprofit Organization

FULL NAME

ADDRESS

Individual       Small Business Concern       Nonprofit Organization

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

NAME OF PERSON SIGNING Claude FEUERSTEIN

TITLE OF PERSON OTHER THAN OWNER President

ADDRESS OF PERSON SIGNING UNIVERSITE JOSEPH FOURIER

621, Avenue Centrale, B.P. 53 X, 38041 GRENOBLE CEDEX, FRANCE

SIGNATURE  DATE May 8, 2001

Claude FEUERSTEIN



09/831170

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1/PRTS

METHOD AND DEVICE FOR DETERMINING THE CENTER OF A JOINT

The present invention aims at locating the center of rotation of a rigid organ with respect to a determined point of this organ. The present invention finds applications in complex mechanical systems where it is practically impossible to determine by direct calculation the motion of given organs with respect to other. It especially finds applications in the case of rigid organs of the human body, such as bones, and will be more specifically described hereafter in the context of the determination of the center of rotation of a revolute joint, and more specifically still in the context of the determination of the center of a femoral head.

For many human body motion analysis, diagnosis, or surgical operations, it is previously required to accurately determine the position of the center of a femoral head with respect to a referential linked to a patient's femur or pelvis. It should be noted that this determination in itself is not a diagnosis operation, nor a medical or surgical operation. It has no effect on the considered organ and may be performed on a healthy organ, to analyze its motion and, for example, foresee the athletic capacities of an individual. Further, even if it is used with a view to diagnosis or with a medical or surgical aim, it is only an accessory thereof, in the same way as a doctor

needs to know the size and weight of a patient as diagnosis elements.

5 A method for determining the center of rotation of a femur with respect to the pelvis is for example described in international patent application WO-98/40037 published on September 17, 1998, and assigned to Aesculap Company.

10 This patent application provides, to determine the center of rotation of a femur with respect to a pelvis, use of several markers provided with light-emitting diodes driven into bones of the patient. The markers are associated with known systems of localization by triangulation. A first marker is fastened in the femur and a second marker is fastened in the iliac bone. The femur is moved according to several positions. Each of the positions of the first marker is detected by using a 15 triangulation system and is stored in a calculator, taking into account the displacement of the marker fastened in the iliac bone. The invariant distance between the marker linked to the femur and the center of rotation of the femoral head can then be searched by various conventional mathematical minimization methods using for example least error squares algorithms.

20 This system has provided full satisfaction, but it has the disadvantage of requiring implantation of rigid objects into the femur and the iliac bone and thus provision of incisions.

25 The present invention aims at avoiding at least the implantation in the iliac bone.

To achieve this object, the present invention provides a method for determining the center of rotation of a bone in a revolute joint, including the steps of displacing said bone, locating several ones of its positions, and memorizing them; 30 imposing a constraint to the displacement of said center of rotation without for all this immobilizing it; and searching a point linked to the referential of said bone for which an optimization criterion taking into account said constraint is reached.

According to an embodiment of the present invention, 35 applied to the determination of the center of rotation of a first

femur with respect to the iliac bone, the method includes the steps of immobilizing the second femur, displacing the first femur and locating several ones of its positions, and searching the invariants of this displacement, taking into account the fact  
5 that the center of rotations of the first and second femurs are distant by a substantially constant length.

According to an embodiment of the present invention, the method further includes the step of locating upon each measurement of the position of the first femur the position of the  
10 second femur to accordingly correct the position of the center of rotation between the first femur and the iliac bone.

According to an embodiment of the present invention, applied to determining the center of rotation of a first femur with respect to the iliac bone, the method includes the steps of displacing the thigh so that said center of rotation moves along  
15 a trajectory which is clearly mathematically distinct from all other points of the lower femur portion, and searching this point having a specific trajectory by an optimization method.

According to an embodiment of the present invention,  
20 the thigh is moved so that the knee follows a loop trajectory, whereby only the trajectory of the center of rotation will optimize a distance in the expression of which the number of loops and some of their mathematical characteristics will be involved.

According to an embodiment of the present invention,  
25 the thigh motion can be decomposed in several elementary motions, for each elementary motion, an optimal center of rotation and an optimized distance value are calculated, and the center of rotation is statistically defined, taking into account each of  
30 the estimations of the center of rotation and of the optimized distance value, obtained based on each of the elementary motions.

According to an embodiment of the present invention, applied to determining the center of rotation of a first femur with respect to the iliac bone, the method includes the steps of moving the thigh so that its lower portion describes as simple a  
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trajectory as possible, including, in particular, no loops, so that the searched center of rotation describes a mathematically simple trajectory, and searching this point with a mathematically simple trajectory by an optimization method.

5 According to an embodiment of the present invention, the thigh motion can be decomposed in several elementary motions, for each elementary motion, an optimal center of rotation and the value of the optimized distance are calculated, and the center of rotation is statistically defined, by taking into account each of  
10 the estimations of the center of rotation and of the value of the optimized distance, obtained based on each of the elementary motions.

According to an embodiment of the present invention, applied to determining the center of rotation of a first femur  
15 with respect to the iliac bone, the method includes the steps of performing a succession of elementary motions of the thigh, for each of these motions, searching the position of the center of rotation of the femur, assuming that said femur has remained fixed, and determining a confidence ellipsoid within which the  
20 probability of presence of the femur center of rotation is high, and calculating based on the confidence ellipsoids the position of maximum probability of the femur center of rotation.

According to an embodiment of the present invention, some of the elementary motions of the thigh are performed in a  
25 plane and are of small amplitude.

According to an embodiment of the present invention, some of the elementary motions of the thigh are performed by rotating the femur around its own axis.

The present invention also provides a device for deter-  
30 mining the center of rotation of a femur with respect to the iliac bone, including means for locating several positions of the femur during motions thereof, means for imposing a constraint to the motion of said center of rotation without for all this immobilizing it, and calculation means for searching a point

linked to the referential of said femur for which a minimization criterion is reached, taking said constraint into account.

The foregoing objects, features and advantages of the present invention will be discussed in detail in the following 5 non-limiting description of specific embodiments in connection with the accompanying drawing, which very schematically shows a lower portion of the person's skeleton.

More specifically, the single drawing shows iliac bone 1 and its right 2 and left 3 acetabuli (it should be noted that 10 the right acetabulum appears on the left-hand side of the drawing, which is a front view) in which are engaged heads 4 and 5 of right and left femurs 6 and 7. The starting of tibias 8 and 9 and kneecaps 10 and 11 have also been shown.

A simple way of determining the center of rotation of a 15 femur, that is, substantially the center of femoral head, would consist, as indicated in the above-mentioned patent application, of measuring several successive positions of the femur while the pelvis, and more specifically the iliac bone, are immobilized. A vector having an invariant top can thus be determined and the end 20 of this vector indicates the center of rotation.

The locating of the femur position may be performed in various ways. In particular, systems for locating the position of transmitters - such as optical or infrared transmitters, but 25 which could also be transmitters radiating at other wavelength or magnetic transmitters - which use sets of sensors and determine the position of each of the transmitters by triangulation, are known. An example of such an installation applied to the determination 30 of the head position is described in the article of Innovation et Technologie en Biologie et Médecine (ITBM) journal, volume 13, N°4, 1992, by L. Adams et al., pages 410-424. There also exist systems sold under trade name "Optotrak" by Northern Digital Company.

Unfortunately, such a simple system poorly operates since it is very difficult to immobilize the pelvis of a patient 35 laying on his back and, when his leg is moved, especially due to

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the elasticity of the skin and muscles between the iliac bone and the table on which the patient lies, the pelvis is inevitably moved. Thus, as described in the preceding patent application, a second localization system or marker inserted in the iliac bone 5 has to be used. This requires performing an incision into the skin and piercing the iliac bone to fixedly position a marker therein. The present invention essentially aims at suppressing this step.

The present invention provides a system that avoids implantation of a marker into the iliac bone and which does not require perfect pelvis immobilization. Generally, the present invention provides imposing constraints to the pelvis motions by various physical processes and deducing from these physical constraints mathematical characteristics of the trajectory of the center of rotation enabling identification thereof.

In a first embodiment the present invention is based on the two following observations. The first observation is that, if it is very difficult to immobilize the pelvis of a patient lying on his back, it is however possible to immobilize his thigh, and thus his femur, by mechanical, pneumatic or vacuum systems, which compress and block the thigh or knee. The second observation is that, given the structure of the human body, it is possible to fasten an external marker against the femoral condyles, the position of this marker remaining perfectly fixed with respect to 25 the femur.

In this first embodiment of the present invention, to measure the position of the center of a femur head, for example left femur head 5, the present invention provides attaching the patient's opposite thigh, containing femur 6. Thus, right femur 30 head 4 remains fixed. The only possible motions of the iliac bone then are rotation motions around this femur head. Designating by C the center of rotation of head 5 of femur 7 and by D the center of rotation of head 4 of femur 6, since point D is fixed, point C can only move on a sphere centered on point D. Thus, a point O attached to femur 7 can only move according to a combination of 35

motions including a rotation of fixed radius around point C, and a rotation of fixed radius of point C around point D.

Knowing several positions of point O and the corresponding femur orientations, the problem to be solved to determine the position of point C is an optimization problem. Various methods for solving this problem may be used: general non-linear least error squares methods, methods adapted to cases where the expression to be minimized is a square of sums of squares, formal calculation methods for solving polynomial equation systems.

Descriptions of these and other methods can be found in the following works:

NAG program library, Numerical Algorithms Group ltd, Wilkinson House, Jordan Hill road, Oxford, UK OX2 8DR,

IMSL program library, International Mathematical and Statistical Library, Visual Numerics inc., 9990 Richmond Suite 4000, Houston, TX 77042, USA,

Régression non linéaire et applications, A. Antoniadis et al., "Economie et Statistiques Avancées" collection, Economica, 1992, France,

Introduction à l'analyse numérique matricielle et à l'optimisation, Masson, 1982, France.

Mathematical methods enabling determination of the positions of center of rotations C and D also enable determination of a certain uncertainty on the result. Especially, a residue indicating whether the considered points really are fixed points appears. If this residue appears to be too large, this means that femur 6 has not been properly immobilized and that point D has moved in the patient's manipulation. To overcome this disadvantage, a marker may be attached to femur 6. As indicated previously, such a marker needs not penetrate into the bone, but can be attached outside of the leg, for example close to the knee against the femoral condyles close to kneecap 10. Thus, for each position of femur 7, the displacement of femur 6, and thus of

point D, can be determined to perform the corresponding correction.

The present invention also provides other means for determining the position of the center of a femur head without requiring driving of a marker into the iliac bone and without requiring immobilization of the pelvis or of the opposite femur, or following its motions. In each of the following embodiments, the position of the femur of which the center of rotation is desired to be located is tracked by a marker and triangulation system of the previously described type.

According to a second embodiment of the present invention, motions of the thigh such that the center of rotation of the femur always moves along a trajectory which is clearly distinct from that of the other points of the lower femur end are performed, and the point having a trajectory that maximizes a distance to the trajectory of the marker attached to the lower part of the femur is searched, by an optimization method of the above-mentioned type. The distance between trajectories may take into account "topological" features (for example, and non-limitingly: number of self-intersections in the trajectory, or in the projections of the trajectory on given sub-spaces such as planes or spheres; number of "loops" thus delimited; relative positions of the covered loops while "looking at" the inside or the outside of said loops, inside and outside being understood in the sense of "Ampere's rule", which is conventional in electricity; number and relative positions of points having specific topological features, such as for example stationary points; etc.) or "energetic" features (for example, and non-limitingly: trajectory length; flexion energy of the trajectory, a conventional linear approximation of which is the integral of the square of the second derivative - see Approximation et Optimisation, Pierre-Jean Laurent, Herman 1972; and generally an integral of expressions involving the curve derivatives at orders ranging to the 3<sup>rd</sup> order or more; etc.). It will be attempted to move the patient's knee so that its lower end describes complex trajectories.

Indeed, the center of rotation will not be able to "follow" these complex motions, and will thus describe a mathematically simpler trajectory, which will enable identifying it. For example, the patient's knee will be moved so that it follows a trajectory

5 including at least one "crossing", an eight for example, or a succession of loops. Then, the trajectories of most femur points will have the shape of an eight or will more generally include one or several crossing points. Only the trajectory of points close to the center of rotation, or even, in certain cases, of  
10 the sole center of rotation, will have no crossing point, or less than the trajectory of the reference marker. Thus, even if the center of rotation is not fixed, this center will be able to be identified with respect to point O as being the only point having a trajectory optimizing a distance to the trajectory of the  
15 reference marker constructed based on the previously-defined "topological" or "energetic" criteria.

According to a third embodiment of the present invention, not one, but several trajectories such as those corresponding to the second mode are performed. The processing of the data characterizing each of these trajectories is performed according to the second mode, which provides several estimates of the center of rotation. The quality of each of these estimates can be estimated by the value of the used optimization criterion. The point retained as a final estimate of the center of rotation is  
20 the result of a statistical processing of this set of estimates, taking into account quality indicators of these estimates (for example, weighted average, non-linear statistical processings, median filtering, etc.).

According to a fourth embodiment of the present invention, motions of the thigh such that its lower part moves according to as "simple" a trajectory as possible, that is, exhibiting none of the topological features used in the second embodiment, and in particular no loops, are performed. The center of rotation of the femur will then be determined as being the femur point having a trajectory minimizing the "energetic" criteria intro-

duced in the description of the second mode. The same optimization methods may be applied. This determination of the center of rotation may however depend on the way in which the thigh rotating motions are transmitted to the iliac bone. Now, this  
5 transmission depends on the way in which is urged the thigh, on which compression (force pushing the femur to the pelvis) or traction (force tending to draw the femur away from the pelvis) may simultaneously be exerted for a given stress causing the rotation. To eliminate this effect, motions of the thigh  
10 alternating compression and traction may thus be performed.

According to a fifth embodiment of the present invention, not one, but several trajectories such as those corresponding to the fourth mode are followed. The processing of the data characterizing each of these trajectories is performed according  
15 to the fourth mode, which provides several estimates of the center of rotation. The quality of each of these estimates can be estimated by the value of the used optimization criterion. The point retained as a final estimate of the center of rotation is the result of a statistical processing of this set of estimates,  
20 taking into account quality indicators of these estimates (for example, weighted average, non-linear statistical processings, median filtering, etc.).

According to a sixth embodiment of the present invention, a succession of elementary motions of the thigh are performed. For each of these motions, the position of the femur center of rotation is searched, assuming that it has remained fixed, and a confidence ellipsoid within which the probability of presence of the femur center of rotation is high, for example greater than 95%. Based on several of these confidence ellipsoids, the position of maximum probability of the femur center of rotation is calculated. Each of the confidence ellipsoids is estimated in a referential linked to the femur: possible motions of the femur between the elementary motions are thus allowed for and will not adversely affect the accuracy of the determination  
30 of the searched center of rotation. As an example of motions of  
35

the thigh adapted to implementing this method, motions with a low  
urge of the ligamentary, capsular, and muscular apparatus ensur-  
ing the cohesion between the femur and the pelvis may be chosen.

Such motions are for example rotating motions of the femur around  
5 its axis, or motions where the femur end moves with a suffi-  
ciently limited amplitude, describing for example approximately  
in a plane a portion of a circle, said plane being likely to  
contain, for example, approximately the center of rotation or to  
be approximately perpendicular to the axis formed by the center  
10 of rotation and the center of said circle. For this method to be  
operative, each of the confidence ellipsoids must be sufficiently  
small, as least in one dimension. Given that present calculators  
provide such ellipsoids practically in real time, if, after a  
15 motion, too large an ellipsoid is obtained, the operator will  
cancel the obtained result and perform a new motion, for example,  
of smaller amplitude or according to one of the other suggested  
modes.

The present invention has been described in detail in  
relation with a method for determining the center of rotation of  
20 a femur. It should be noted that, except for the first described  
embodiment, it more generally applies to the determination of the  
center of rotation of a bone in a revolute joint.

CLAIMS

1. A method for determining the center of rotation of a bone in a revolute joint, characterized in that it includes the steps of:

5 displacing said bone, locating several ones of its positions, and memorizing them,

imposing a constraint to the displacement of said center of rotation without immobilizing it, and

10 searching a point linked to the referential of said bone for which an optimization criterion taking into account said constraint is reached.

2. The method for determining the center of rotation of a first femur with respect to the iliac bone of claim 1, characterized in that it includes the steps of:

immobilizing the second femur,

15 displacing the first femur and locating several ones of its positions,

searching the invariants of this displacement, taking into account the fact that the center of rotations of the first and second femurs are distant by a substantially constant length.

20 3. The method of claim 2, characterized in that it further includes the step of locating upon each measurement of the position of the first femur the position of the second femur to accordingly correct the position of the center of rotation between the first femur and the iliac bone.

25 4. The method for determining the center of rotation of a femur with respect to the iliac bone of claim 1, characterized in that it includes the steps of:

displacing the thigh so that said center of rotation moves along a trajectory which is clearly mathematically distinct from all other points of the lower femur portion,

30 searching this point having a specific trajectory by an optimization method.

5. The method of claim 4, characterized in that the thigh is moved so that the knee follows a loop trajectory, whereby

only the trajectory of the center of rotation will optimize a distance in the expression of which the number of loops and some of their mathematical characteristics will be involved.

6. The method for determining a the center of rotation  
5 of a femur with respect to the iliac bone of claim 4, characterized  
in that:

the thigh motion can be decomposed in several elementary motions,

10 for each elementary motion, an optimal center of rotation  
and an optimized distance value are calculated,

the center of rotation is statistically defined, taking  
into account each of the estimations of the center of rotation and  
of the optimized distance value, obtained based on each of the  
elementary motions.

15 7. The method for determining the center of rotation  
of a femur with respect to the iliac bone of claim 1, characterized  
in that it includes the steps of:

moving the thigh so that its lower portion describes as  
simple a trajectory as possible, including, in particular, no  
20 loops, so that the searched center of rotation describes a mathe-  
matically simple trajectory, and

searching this point with a mathematically simple trajec-  
tory by an optimization method.

8. The method of claim 7, characterized in that:  
25 the thigh motion can be decomposed in several elementary  
movements,

for each elementary motion, an optimal center of rotation  
and the value of the optimized distance are calculated,

30 the center of rotation is statistically defined, by  
taking into account each of the estimations of the center of rota-  
tion and of the value of the optimized distance, obtained based on  
each of the elementary motions.

9. The method for determining the center of rotation  
of a femur with respect to the iliac bone of claim 1, characterized  
35 in that it includes the steps of:

performing a succession of elementary motions of the thigh,

for each of these motions, searching the position of the center of rotation of the femur, assuming that said femur has remained fixed, and determining a confidence ellipsoid within which the probability of presence of the femur center of rotation is high, and

calculating based on the confidence ellipsoids the position of maximum probability of the femur center of rotation.

10. The method of claim 9, characterized in that some of the elementary motions of the thigh are performed in a plane and are of small amplitude.

11. The method of claim 9, characterized in that some of the elementary motions of the thigh are performed by rotating the femur around its own axis.

12. A device for determining the center of rotation of a femur with respect to the iliac bone, characterized in that it includes:

means for locating several positions of the femur during motions thereof,

means for imposing a constraint to the motion of said center of rotation without for all this immobilizing it, and

25 calculation means for searching a point linked to the referential of said femur for which a minimization criterion is reached, taking said constraint into account.

I/I

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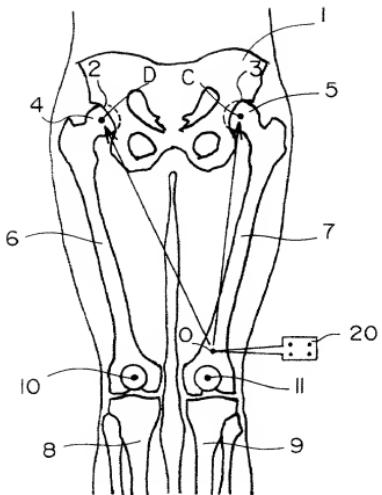


Fig 1

09/831170 - 0982001

Docket No. \_\_\_\_\_

**Declaration and Power of Attorney For Patent Application****English Language Declaration**

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

**METHOD AND DEVICE FOR DETERMINING THE CENTER OF A JOINT**SEARCHED  
INDEXED  
MAILED  
FILED  
RECEIVED  
SEARCHED  
INDEXED  
MAILED  
FILED  
RECEIVED

the specification of which  
(check one)

is attached hereto.

was filed on MAY 4, 2001 as United States Application No. 09/831,170 PCT International

Application Number 09/831,170

and was amended on \_\_\_\_\_

(if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d) or Section 365(b) of any foreign application(s) for patent or inventor's certificate, or Section 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate or PCT International application having a filing date before that of the application on which priority is claimed.

**Prior Foreign Application(s)****Priority Not Claimed**

<u>98/14298</u> (Number)	<u>FRANCE</u> (Country)	<u>10 November 1998</u> (Day/Month/Year Filed)	<input type="checkbox"/>
			<input type="checkbox"/>
			<input type="checkbox"/>

I hereby claim the benefit under 35 U.S.C. Section 119(e) of any United States provisional application(s) listed below:

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(Application Serial No.)

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(Filing Date)

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(Application Serial No.)

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(Filing Date)

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(Application Serial No.)

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(Filing Date)

I hereby claim the benefit under 35 U. S. C. Section 120 of any United States application(s), or Section 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. Section 112, I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, C. F. R., Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application:

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PCT/FR99/02733

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8 November 1999

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(Application Serial No.)

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(Filing Date)

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(Status)  
(patented, pending, abandoned)

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(Application Serial No.)

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(Filing Date)

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(Status)  
(patented, pending, abandoned)

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(Application Serial No.)

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(Filing Date)

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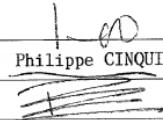
(Status)  
(patented, pending, abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

**POWER OF ATTORNEY:** As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. (*list name and registration number*)

Send Correspondence to:

Direct Telephone Calls to: (*name and telephone number*)

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Full name of fourth inventor, if any	
Fourth inventor's signature	Date
Residence	
Citizenship	
Post Office Address	

Full name of fifth inventor, if any	
Fifth inventor's signature	Date
Residence	
Citizenship	
Post Office Address	

Full name of sixth inventor, if any	
Sixth inventor's signature	Date
Residence	
Citizenship	
Post Office Address	